(On the trail of) A case for forward instrumentation in A+A collisions at RHIC

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ISU fSPHENIX workshop, March 12, 2016

Outline

Motivation

Theory progress

Example measurements

Thoughts going forward (npi)

Summary

From PWS at CIPANP 2012,
"Think Outside the Plasma"

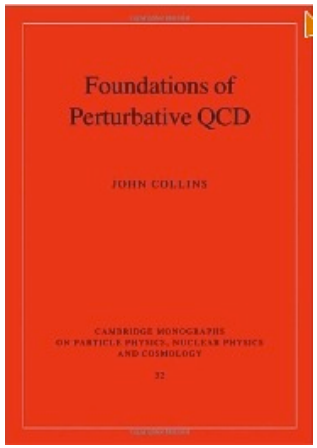
We should expand beyond a narrow (myopic?) focus on the equilibrium and near-equilibrium properties of the QGP.

There's a lot of interesting & fundamental, non-perturtbative and non-equilibrium QCD that *we can now investigate systematically* using high-energy heavy ion collisions.

Three Eras of QCD

Era I: Perturbative QCD

Great successes include running of α_s and evolution of hadron structure functions



Literally a textbook subject

Era II: Thermal QCD

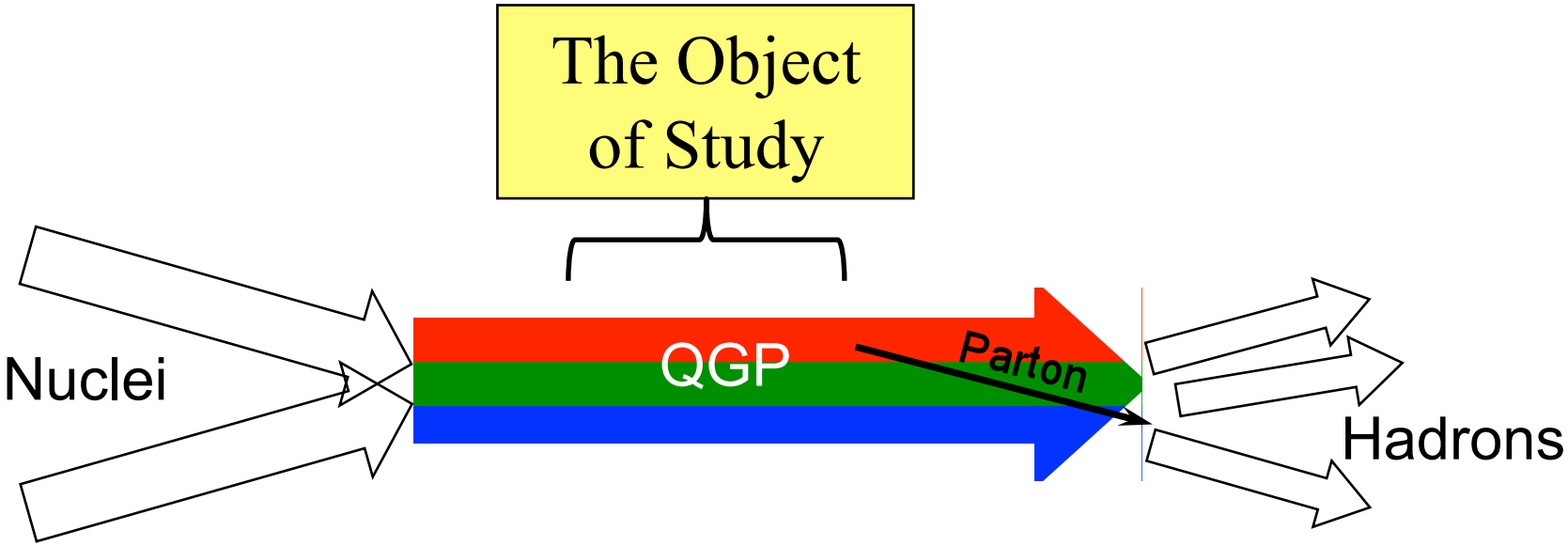
The QGP state of matter: state -> static -> equilibrium, but near-equilibrium (transport) properties are very interesting

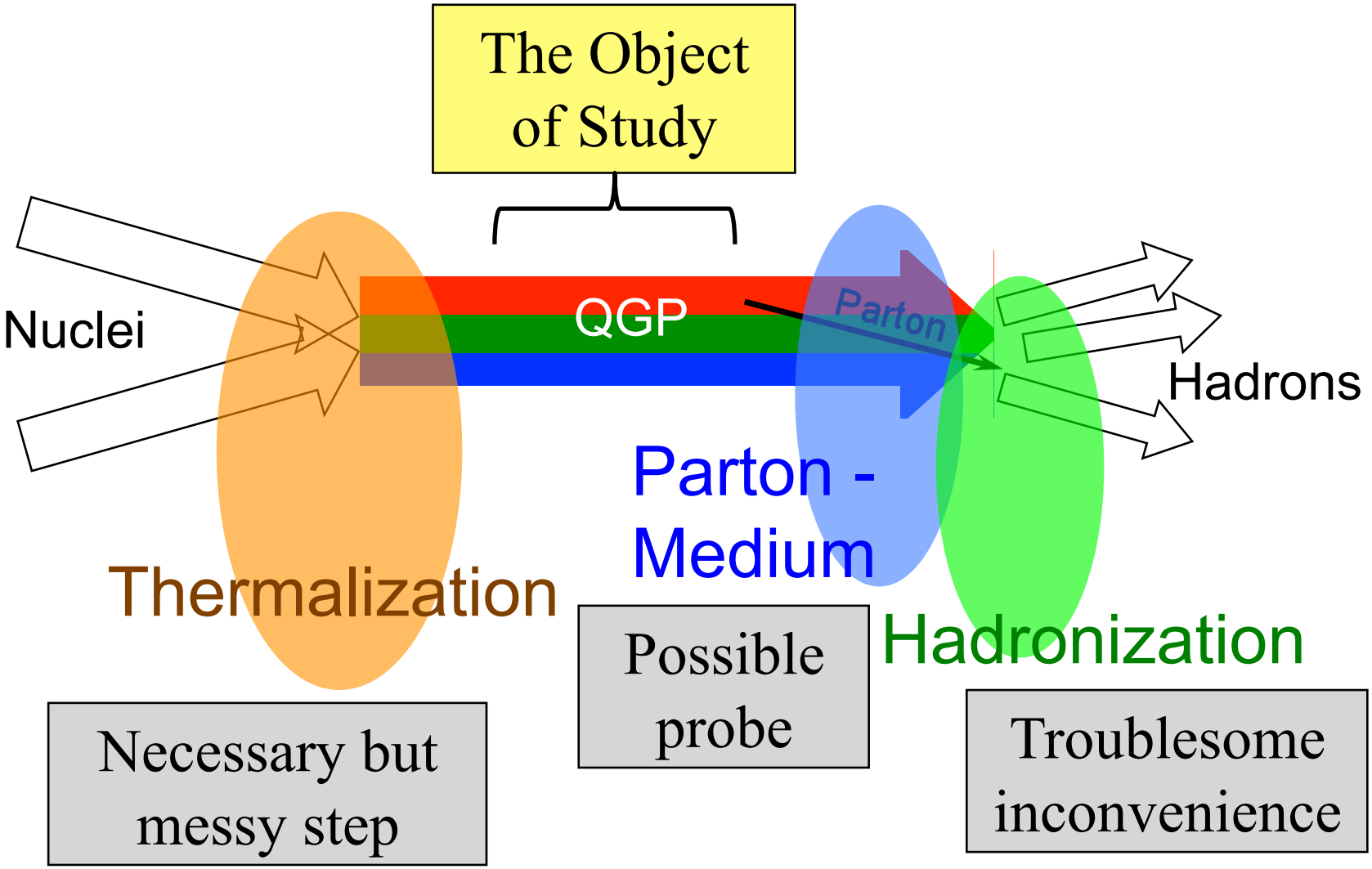
Text coming soon?

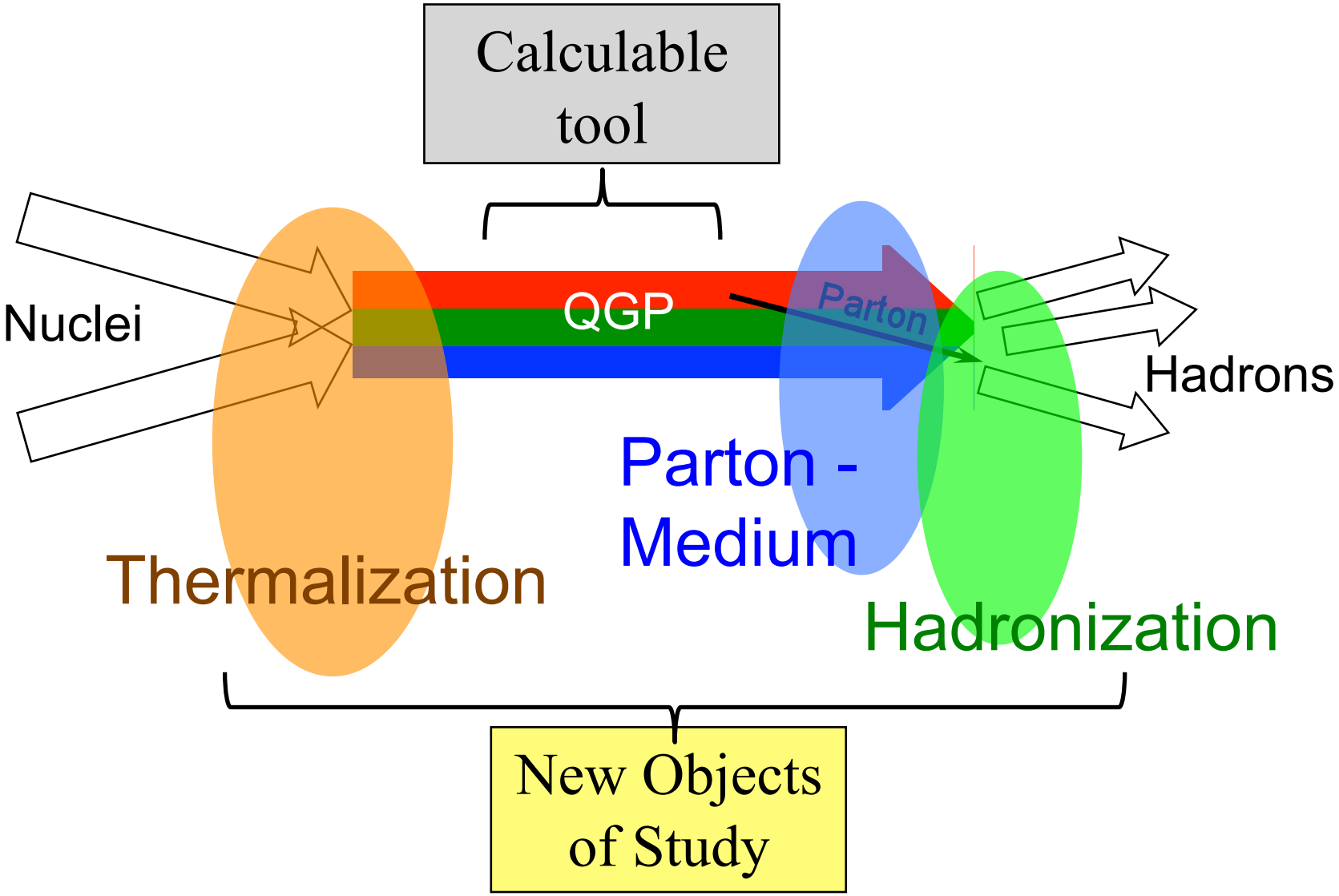
Era III: Non-perturbative, Non-thermal QCD

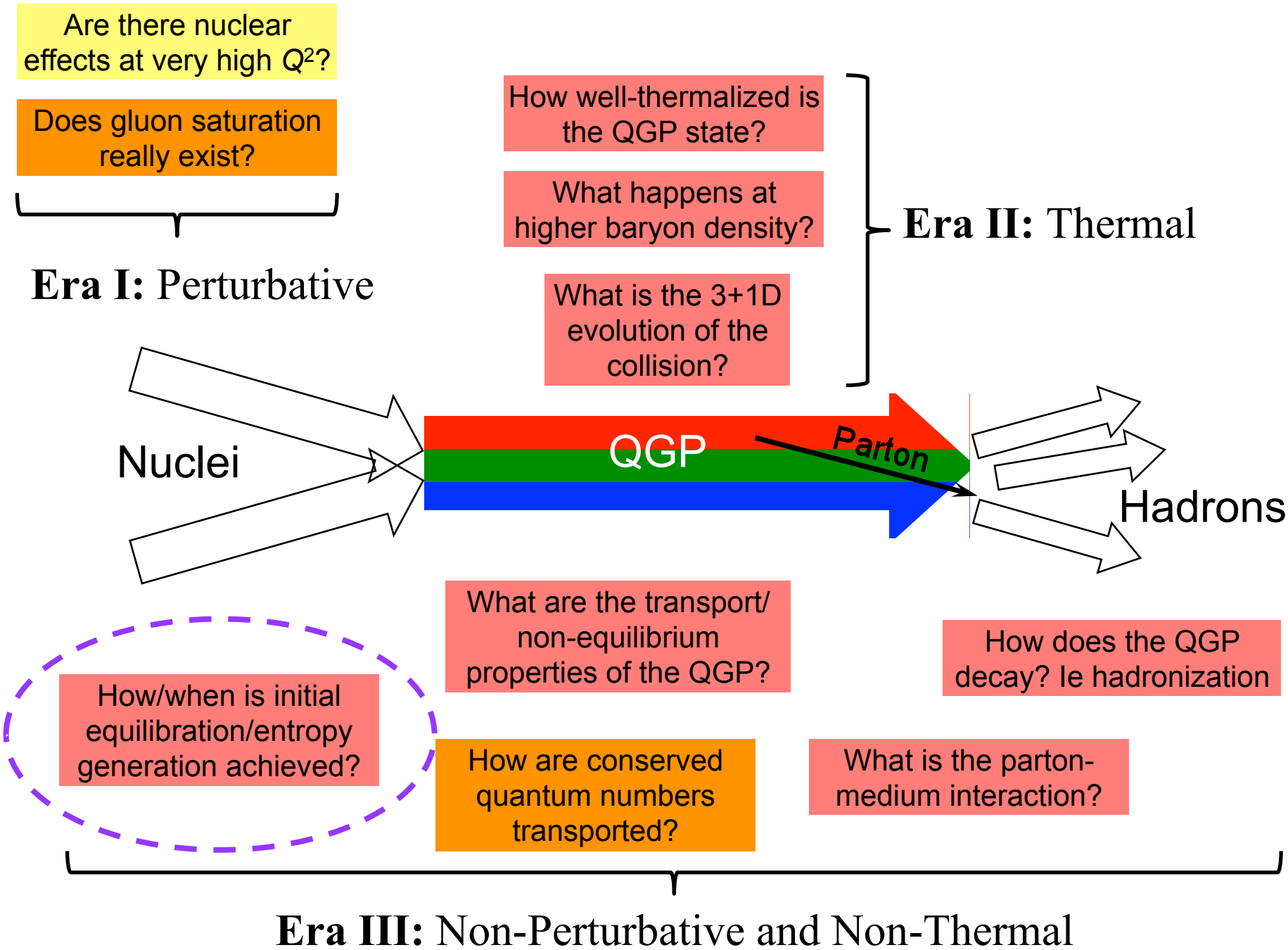
A big tent! that previous successes now enable us to investigate within A+A collisions at RHIC

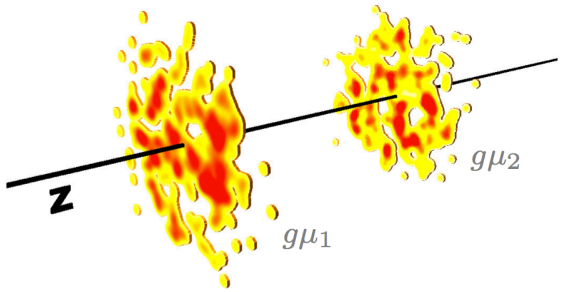
The Stadard-ish Model



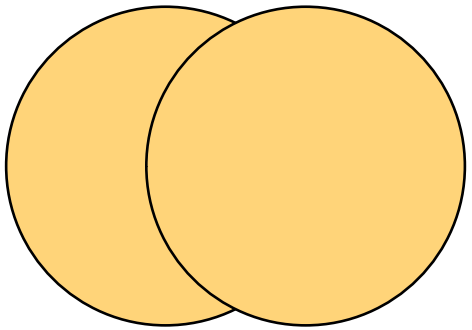

The Object of Study
Nuclei
QGP
Parton
Hadrons
Parton - Medium
Thermalization
Hadronization
Possible probe
Necessary but messy step
Troublesome inconvenience

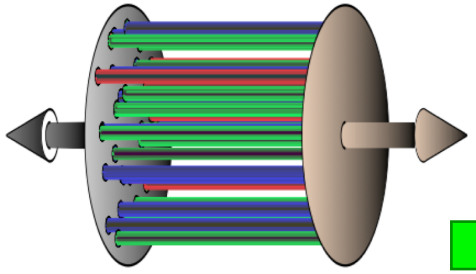

Calculable tool
Nuclei
QGP
Parton
Hadrons
Parton - Medium
Thermalization
Hadronization
New Objects of Study


Are there nuclear effects at very high Q^2?
Does gluon saturation really exist?
Era I: Perturbative
How well-thermalized is the QGP state?
What happens at higher baryon density?
What is the 3+1D evolution of the collision?
Era II: Thermal
Nuclei
QGP
Parton
Hadrons
What are the transport/ non-equilibrium properties of the QGP?
How does the QGP decay? Ie hadronization
How/when is initial equilibration/entropy generation achieved?
How are conserved quantum numbers transported?
What is the parton-medium interaction?
Era III: Non-Perturbative and Non-Thermal



QM

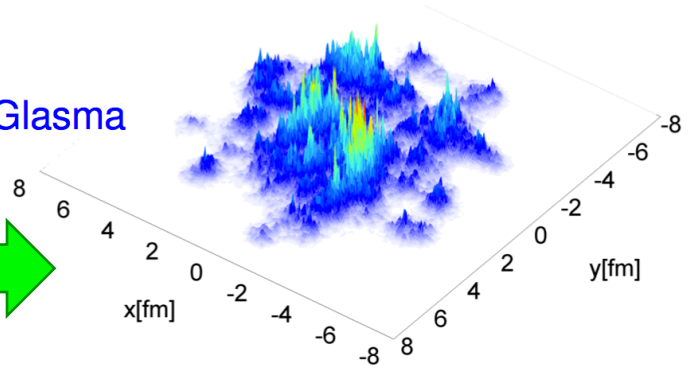




Classical

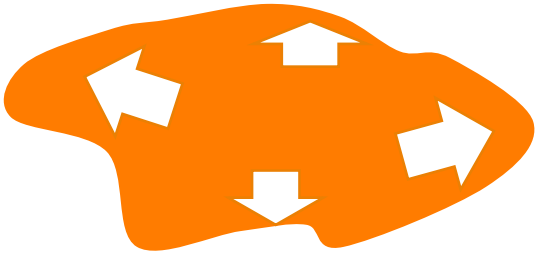
QM

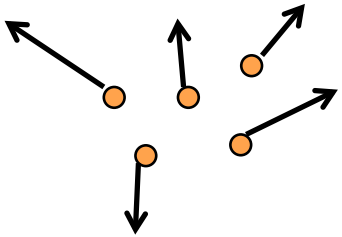
IP-Glasma



Classical

Hydro





QM

An interesting waltz of classical and quantum…

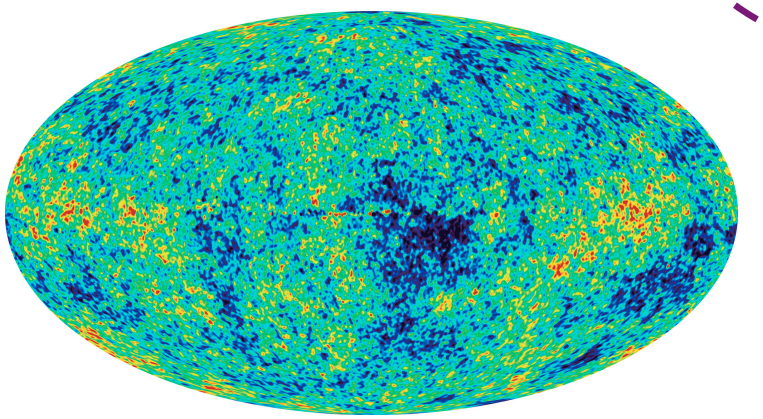
Quantum Fluctuations Made Real

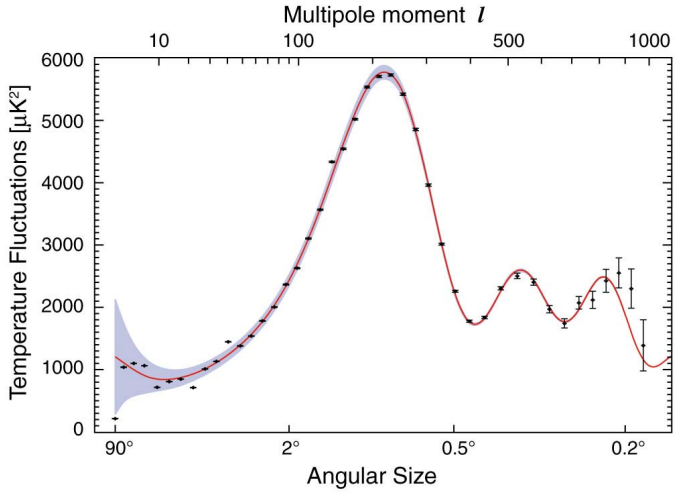
Early Universe

Most Intriguing!

Initial energy density: *quantum fluctuations from a coherent field*

Nuclear Collsion



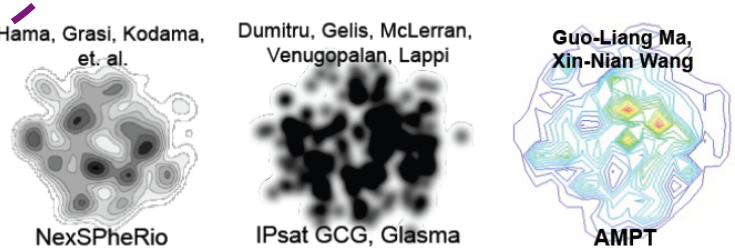


Re-heating/ thermalization

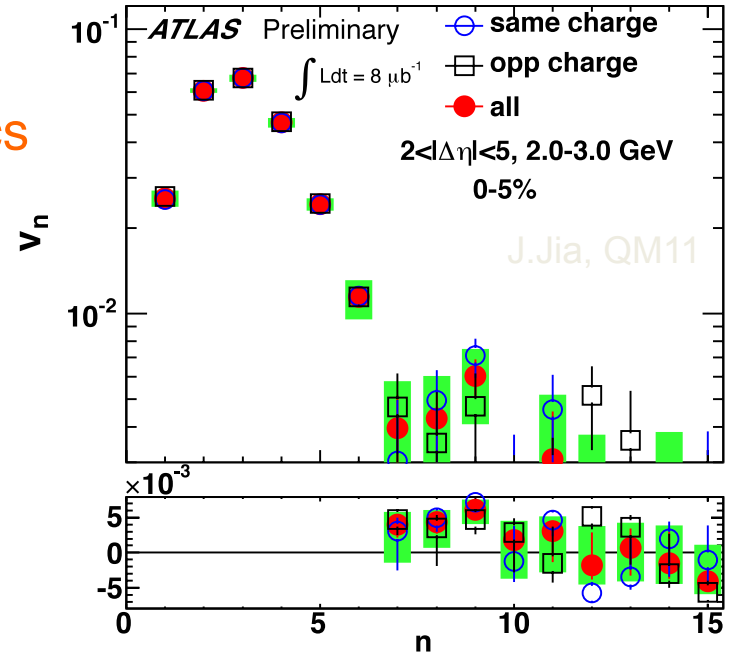
Relativistic hydrodynamics

Freezout/ decoupling

Final-state correlations

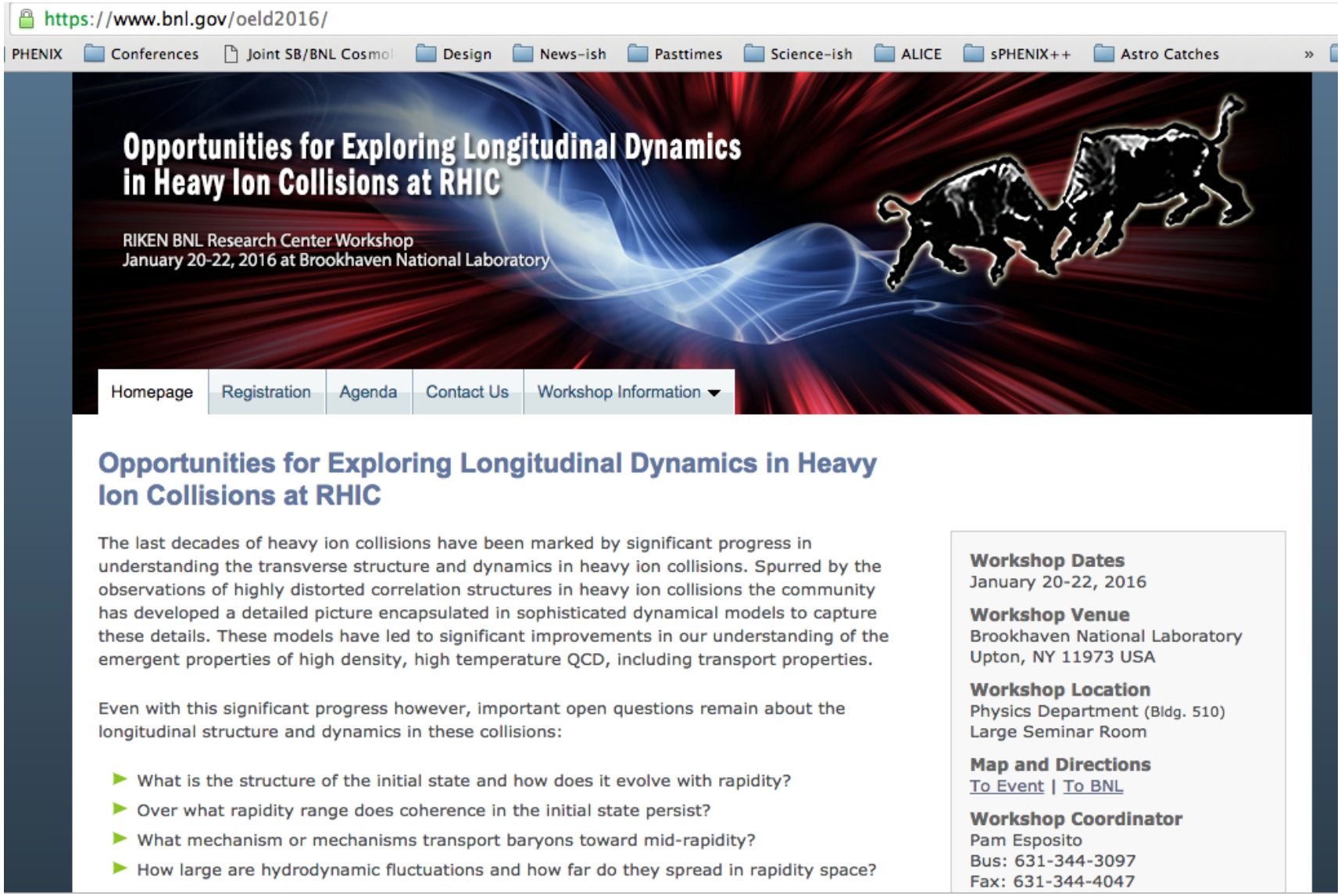


Guo-Liang Ma, QM11



J.Jia, QM11

Theory finally getting interested…



quark.phy.bnl.gov/~kdusling/misc/oeld2016/oeld2016.html

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Opportunities for Exploring Longitudinal Dynamics in Heavy Ion Collisions at RHIC

Wednesday January 20th, 2016

Author	Title	Download
Wei Li	Recent LHC results on rapidity correlations and fluctuations	
Shengli Huang	Forward fluctuations and correlations at RHIC	
Wilke van der Schee	Rapidity Dependence in Holographic Heavy Ion Collisions	
Rainer Fries	Towards the (3+1)-D Structure of Nuclear Collisions	
Soeren Schlichting	Thermalization / Isotropization in heavy-ion collisions	
Heikki Mäntysaari	Longitudinal evolution of small-x gluons	
Adam Bzdak	Longitudinal fluctuations of the medium created in heavy-ion collisions	
Wojciech Broniowski	Rapidity Fluctuations in the Initial State of Ultra-Relativistic Heavy-Ion Collisions	
Yi Yin	Bulk viscous effects near the QCD critical point	

Thursday January 21st, 2016

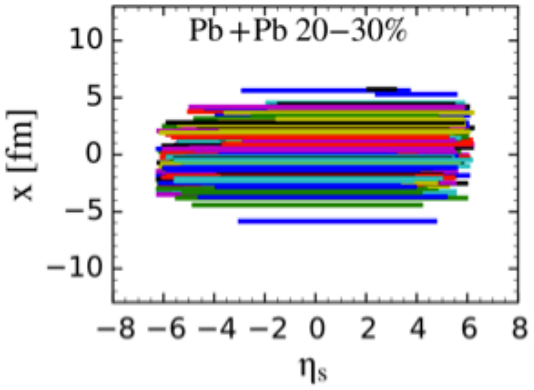
Author	Title	Download

Recommended reading starting points

Fluctuating length

- Idea: entropy deposition from wounded nucleons originates from string-like objects whose other end-point is randomly distributed in η (related to [Brodsky+Gunion+Kuhn 1977])
- *"Soft particle production in hadronic collisions is dominated by multiple gluon exchanges between partons from the colliding hadrons, followed by radiation of ... partons distributed uniformly in rapidity"* [Białas+Jeżabek 2004]
- Torque in p-A collisions (see talk by PB) [PB+WB+Moreira 2011, PB+WB, arXiv:1506.02817]
- Similar ideas in [Monnai+Schenke, arXiv:1509.04103]
- Built-in into existing models/codes

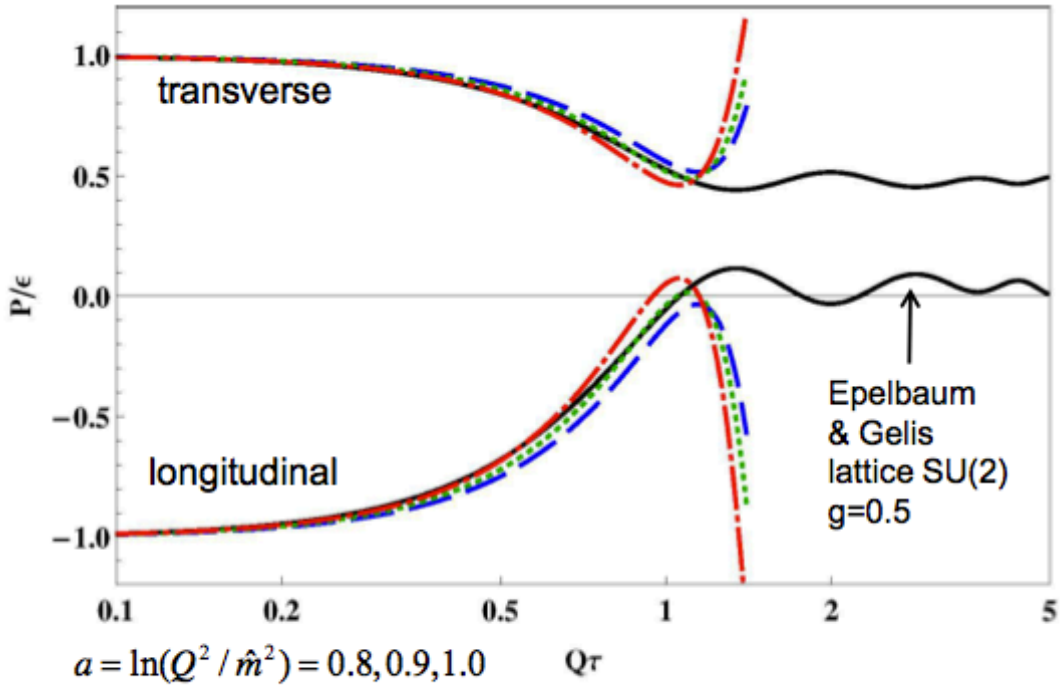
e.g., HIJING [L.-G. Pang, QM2015]:



From W. Broniowski at RBRC-OELD

Results: Bulk Variables

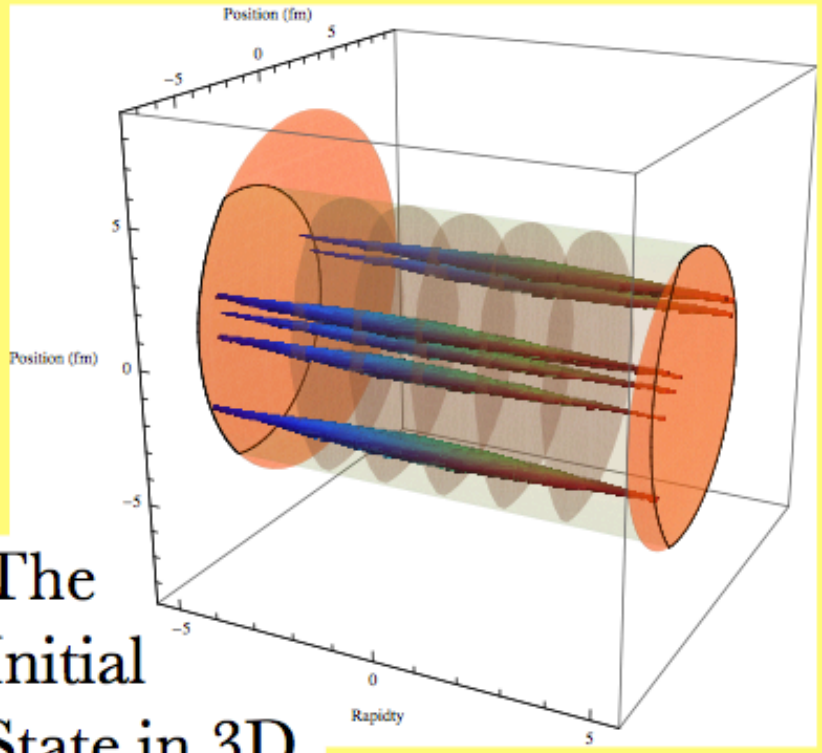
- Our expansion fails around $\tau \sim 1/Q_s$
- Pocket formulas for simple slab nuclei: $\frac{p_L}{p_T} = -\frac{1-\frac{3}{2a}(Q\tau)^2}{1-\frac{1}{2a}(Q\tau)^2} + O(Q\tau)^4$
- Consistent with numerical results



From R. Fries at RBRC-OELD

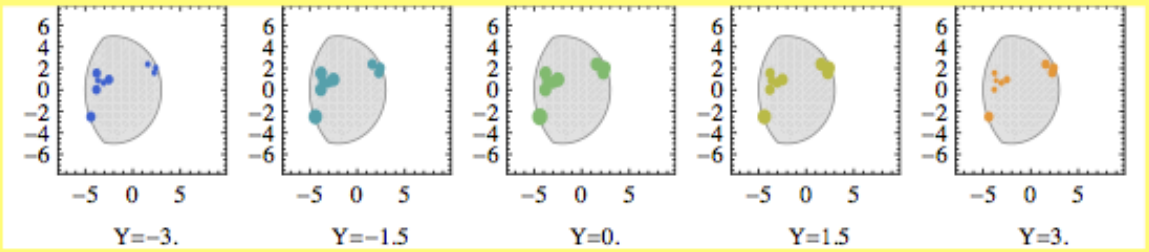
"Club Sandwich" model

PWS poster at QM12
(as yet unpublished)



The Initial State in 3D

The cross section of each "toothpick" tube is proportional to its local energy density dmT/dY at that rapidity/location.

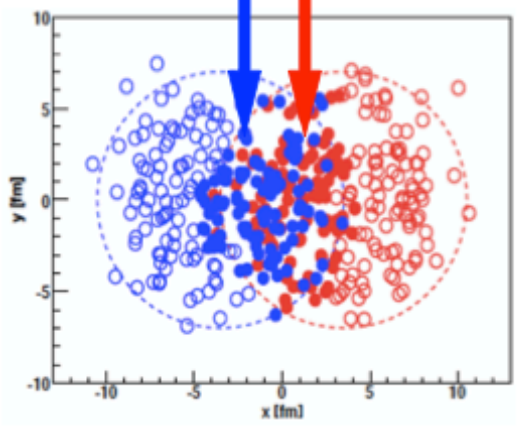


Once the tubes are defined, we can draw the initial energy deposit pattern on any slice of constant energy and constant proper time. This is the full description of a classical object.

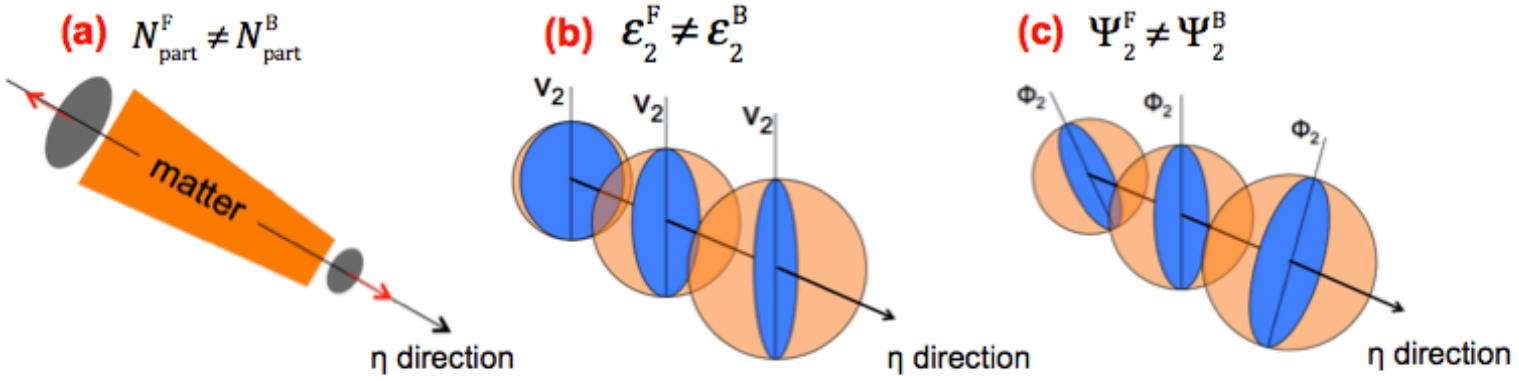
Three types of longitudinal dynamics

Fluctuation participants in two nuclei → difference in size and event-shape

$N^{\mathrm{F}}_{\mathrm{part}}$ $\varepsilon^{\mathrm{F}}_{n} e^{in\Psi^{F}_{n}}$ $N^{\mathrm{B}}_{\mathrm{part}}$ $\varepsilon^{\mathrm{B}}_{n} e^{in\Psi^{B}_{n}}$



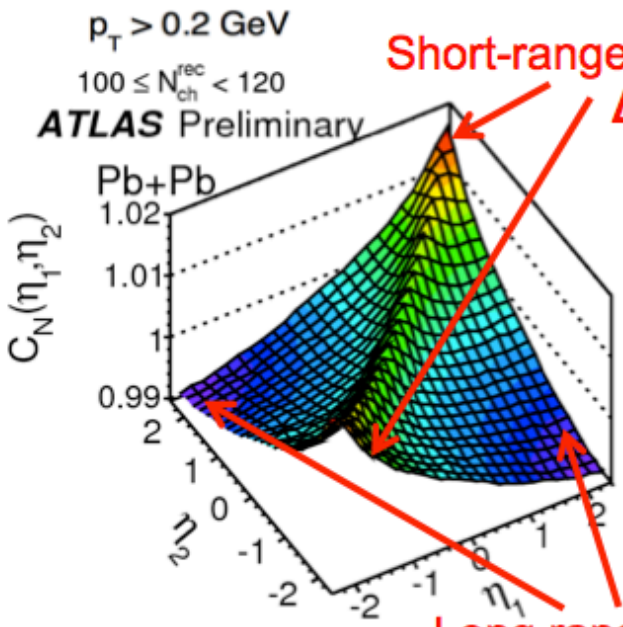
Consequences:



Asymmetry in multiplicity | Asymmetry in flow magnitude | Torque/twist of flow plane

From J. Jia at RBRC-OELD

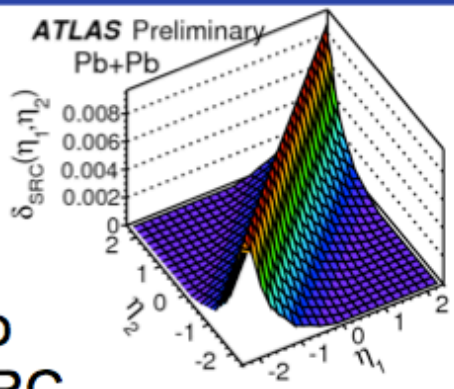
Property of the multiplicity correlation



Short-range correlation $\delta_{\mathrm{SRC}}(\eta_1, \eta_2)$

$\Delta\eta=\eta_1-\eta_2\sim0$

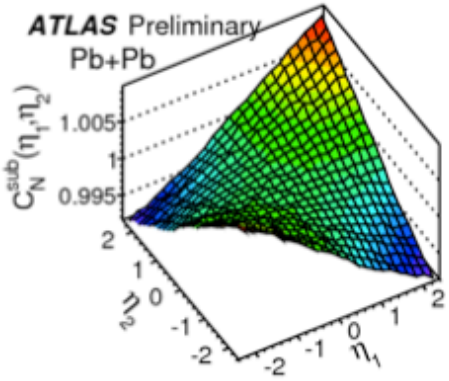
=



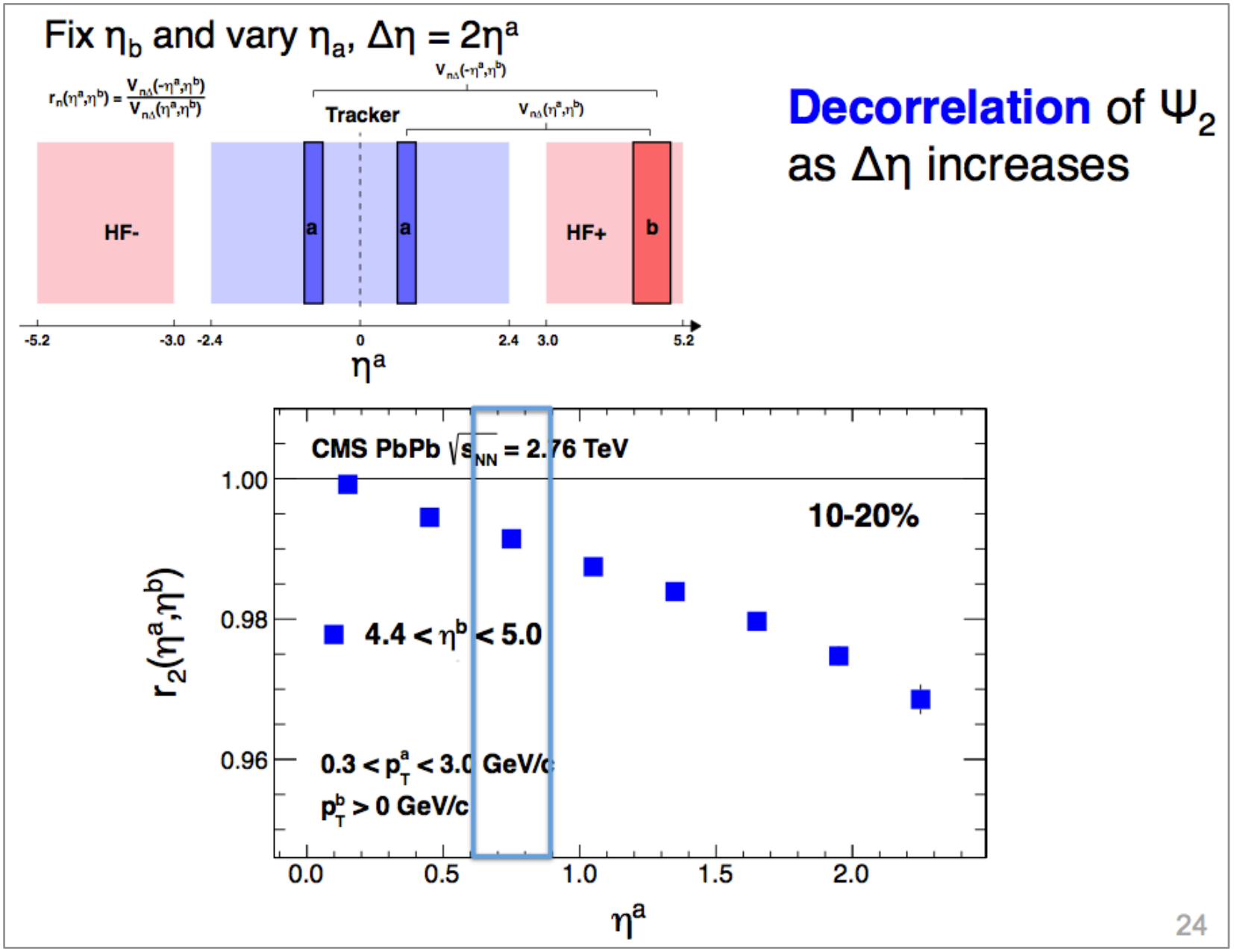
Data-driven method to separate SRC from LRC

Long range correlation $\mathrm{LRC}(\eta_1, \eta_2)$ large $|\Delta\eta|$

=



- SRC reflects correlations in the same source
- LRC reflects FB-asymmetry of number of sources, e.g. $A_{\mathrm{part}} = \dfrac{N_{\mathrm{part}}^{\mathrm{F}} - N_{\mathrm{part}}^{\mathrm{B}}}{N_{\mathrm{part}}^{\mathrm{F}} + N_{\mathrm{part}}^{\mathrm{B}}}$



From W. Li (CMS) at RBRC-OELD

Forward thoughts

- Think outside the plasma! Initial energy deposit and thermalization are a new and distinct sub-field of QCD
- Longitudinal patterns/correlations provide *new information* on initial event profiles
- New combined (forward + mid) – rapidity instrumentation: calorimetery, tracking, PID
- PWS, et.al., toyed for years but nothing solid; someone new needs to pick up the trail

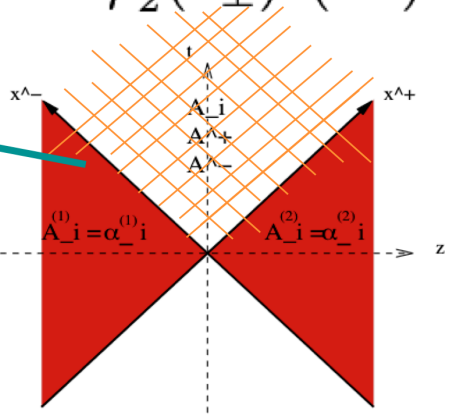
Backup

The Glasma at LO:Yang-Mills eqns. for two nuclei

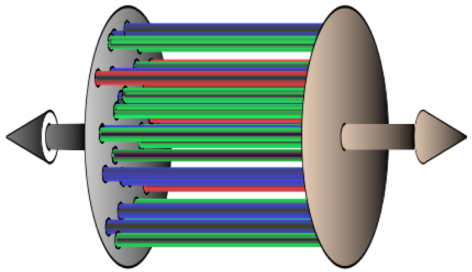
$O(1/g^2)$ and all orders in $(g\rho)^n$

$$D_\mu F^{\mu\nu,a} = \delta^{\nu+}\rho_1^a(x_\perp)\delta(x^-) + \delta^{\nu-}\rho_2^a(x_\perp)\delta(x^+)$$

Glasma initial conditions from matching classical CGC wave-fns on light cone



Kovner,McLerran,Weigert; Krasnitz, RV; Lappi
Lappi,Srednyak,RV (2010)



$$\nabla \cdot E = \rho_{\text{electric}} \qquad \nabla \cdot B = \rho_{\text{magnetic}}$$

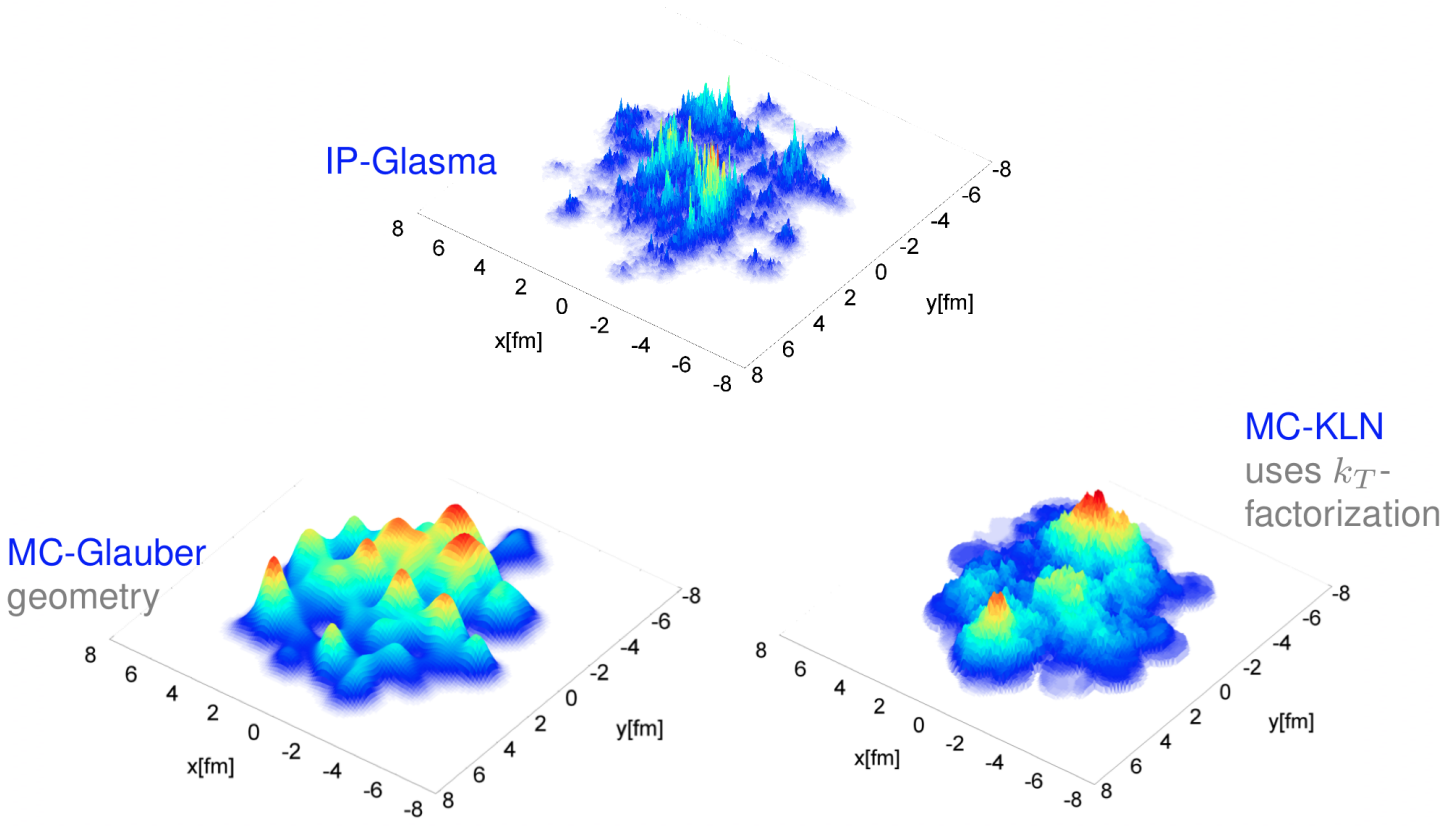
$$\rho_{\text{electric}} = ig[A^i, E^i] \qquad \rho_{\text{magnetic}} = ig[A^i, B^i]$$

Boost invariant flux tubes of size with || color E & B fields- generate Chern-Simons charge

However, this results in very anisotropic ($P_T >> P_L$) pressure for $\tau \sim 1/Q_S$

Lifted from RV, Cape Town lectures Feb 2012

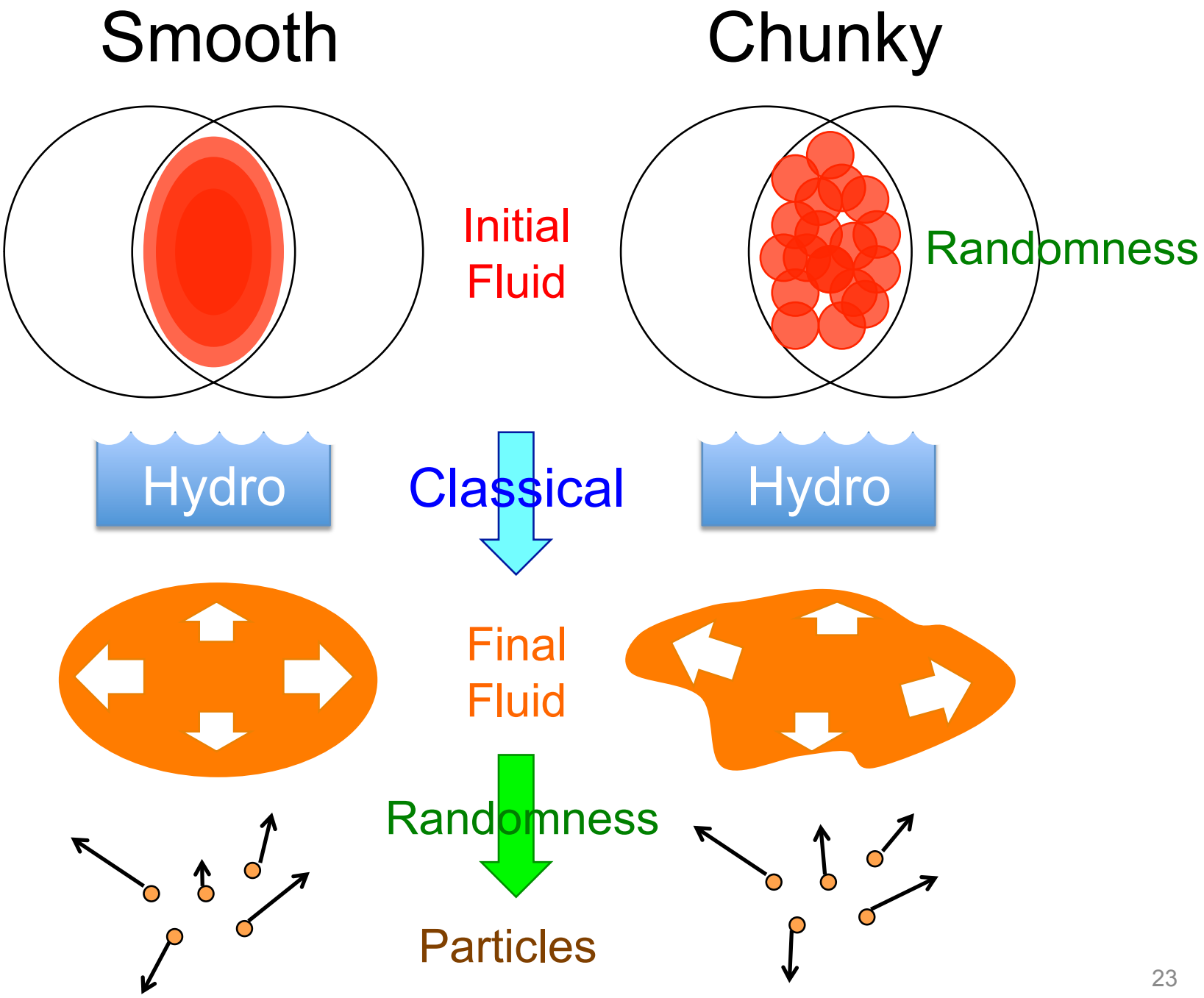
Comparison with other models



MC-KLN: Drescher, Nara, nucl-th/0611017

mckln-3.52 from `http://physics.baruch.cuny.edu/files/CGC/CGC_IC.html` with defaults, energy density scaling

From B. Schenke's talk CIPANP 2012, Friday AM


Smooth
Chunky
Initial
Fluid
Randomness
Hydro
Classical
Hydro
Final
Fluid
Randomness
Particles

Unhidden Agenda (PWS ca 2010)